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RESPONSE TO RAINFALL IN INDIA*

By **LEONARD O. PACKARD**

Boston Normal School, Boston, Mass.

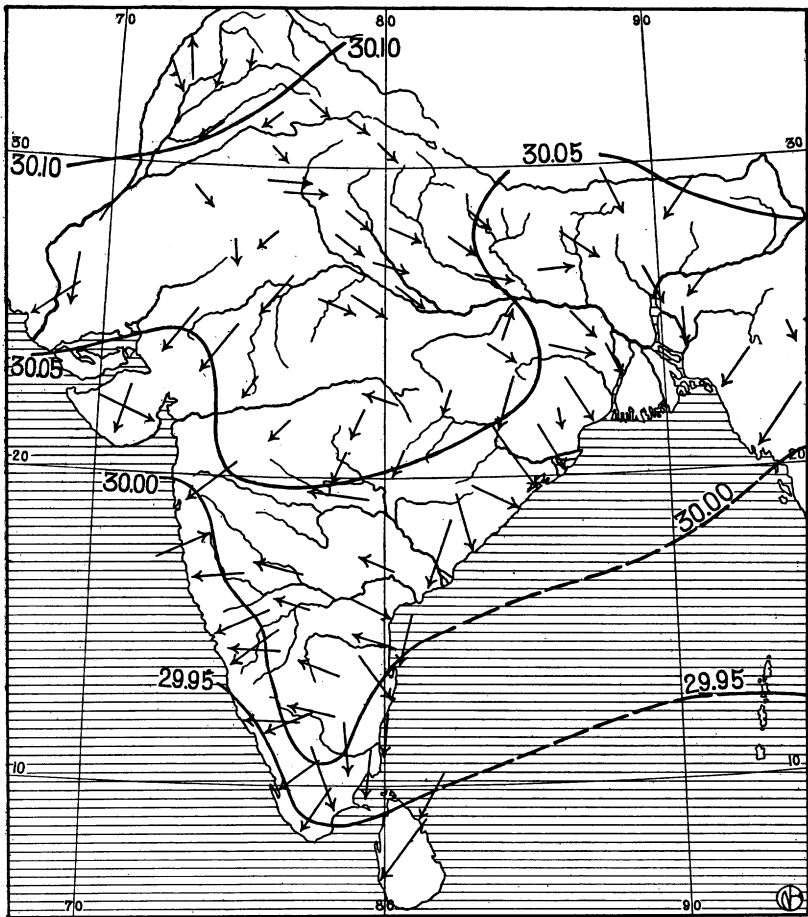
Some effects of rainfall upon the life of man are apparent to the most casual observer. For instance, it is obvious that either through lack of rainfall, as in the Sahara Desert, or because of excessive rainfall, as in the Amazon Valley, the habitable areas of the earth are restricted or rendered exceedingly undesirable as places of human habitation. There are still other parts of the earth in which the precipitation, although more favorable for human habitation, compels man to adapt his life in many of its phases to its peculiar characteristics. The different provinces of India, presenting almost every possibility in the amount and yearly distribution of rainfall, furnish many interesting illustrations of the effects of the rainfall of a region upon the life of the people.

It is the purpose of the present treatment of the subject to note only a few of the more obvious responses of the life of the inhabitants of India to the peculiarities of rainfall of the several parts of the country.

It is necessary first to know something of the controls of the Indian rainfall in order that the distribution and variations of precipitation may be understood. For convenience of discussion, India may be divided into two parts: northern India, consisting largely of the plains of the Ganges and the Indus; and peninsular India, comprising all the rest of the country lying to the south of these plains. This area includes only the mainland as far east as Burma; it does not include Kashmir in the north, or Baluchistan in the west.

* Prepared in the course in Climatological Research given in Harvard University, in 1913, by Prof. R. DeC. Ward.

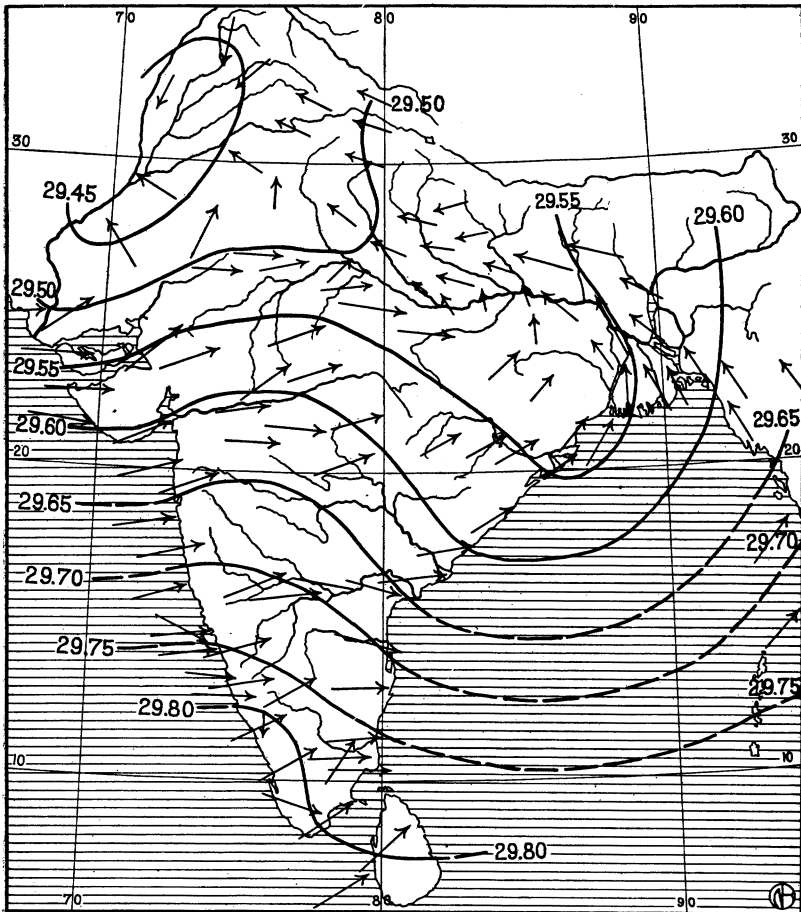
The rainfall of this region is, of course, due to the character of the winds, to cyclonic and other storms, and to peculiarities of topography. As the equatorial belt of low pressure, in its yearly migration, crosses India the deflected southeast trades blow across the country as the southwest monsoon during the summer, while



Average pressure and wind of India—January. (After Eliot.) Scale, 1:27,000,000.

during the winter the northeast trades are the prevailing winds and are known as the winter or northeast monsoon. Except in northern India, which receives precipitation from extra-tropical cyclones, the season of the winter monsoon, which blows from land to sea, is one in which little rain falls. Therefore a study

of the causes of rainfall in India consists very largely of an investigation of conditions prevailing during the summer monsoons. These blow over some part of India from the end of May, when they first appear over the southwest of the peninsula, to the middle of December when they retreat from the Carnatic. During



; Average pressure and wind of India—July. (After Eliot.) Scale, 1:27,000,000.

their greatest northward advance these winds are divided by the Indian peninsula into two parts; one of these approaches the country from the southwest over the Arabian Sea, and the other from the southeast over the Bay of Bengal.

The controls of rainfall produce in much of northern India a

rainfall curve presenting two well-defined maxima. The winter maximum is due to the fact that all of northern India receives some rain from extra-tropical cyclones which appear in the western part of this region and move east along the Ganges valley, giving less and less precipitation as they advance. Some of these storms travel even as far as Burma, where they disappear. The total amount of rain from this source is small, in no case exceeding four inches for any one month. As one would expect, this rainfall also diminishes in quantity from north to south as distance from the highlands increases. Small quantities of rain, however, fall even in central India as these storms pass across country. Winter cyclones are also the chief source of the snowfall of the western Himalayas. The summer rainfall of this region, the cause of the second maximum of the curve, is brought by the south-east branch of the summer monsoon, which blows up the Ganges valley toward the area of lowest pressure in the extreme north-west of India. The distribution of rainfall over the area reached by this monsoon is determined by two causes: one, the distance from the sea from which the wind blows; the other, the elevation of the land. As results of these two influences, the rainfall is heavier in the eastern portion of northern India than in the western, and heavier near the Himalayas than on the plains farther south. Another source of rainfall in this region is the tropical cyclones which move from the Bay of Bengal to the west or north-west, frequently continuing as far as central India, and occasionally to the Punjab and Sind. The effect of the passage of such cyclones across the country is to draw the moisture-laden winds from considerable distances toward the center of the storm, thus increasing the rainfall of the region over which the storm passes. On the other hand, by interfering with the normal flow of winds of adjacent regions, these storms often produce "breaks in the rains" in those regions.

Adding the topography of the country to these controls of rainfall, *viz.*, the extra-tropical cyclones, the summer monsoons and the cyclones accompanying these monsoons, we have all the conditions necessary to explain the rainfall of northern India. The precipitation of Bengal and Assam, as shown by the rainfall map, is by far the heaviest of this part of the country, and at one place, Cherrapunji, is the heaviest in the world. The explanation of this fact is the nearness of these provinces to the sea from which the wind blows for a period of four months or more with little interruption. Moreover, that portion of the Bay of Bengal which

is nearest this region is the one from which the tropical cyclones most frequently advance upon the land, hence this area receives more rain from this source than any other part of India. The heaviest rainfall, that of Cherrapunji, occurs on the windward side of the Khasi Hills where the warm, moisture-laden winds are forced up at a distance of not more than 200 miles from the sea. The fact that the altitude of Cherrapunji is about that of the zone of maximum rainfall is another reason for the exceptionally heavy precipitation of that place.

In order to be understood, the exceedingly light rainfall of parts of Rajputana and Sind requires more careful explanation. In addition to their great distance from the Bay of Bengal, the slight elevation of the region, which varies from 49 feet above sea level at Karáchi to 420 feet at Multan, is a determining factor, as well as the temperature, which during the season of summer monsoons is very high. Again, in summer this is the region of the trough of low pressure about which the winds move in a counter-clockwise direction. In consequence, the winds blowing over portions of this province, particularly the plains of Sind and western Rajputana, have their origin in part at least over the lands to the west and therefore carry little moisture. The winds coming from the sea are deflected to the east of the low-pressure area, and do not ascend until they reach the highlands to the north.

Much the same factors as control the distribution of rainfall in northern India are responsible for the varying amounts of precipitation in the northern part of peninsular India, with the exception that the latter region receives rain from both branches of the summer monsoon. Throughout the greater part of the rainy season the winds of these provinces are west winds blowing from the Arabian Sea. However, the wind and rainfall charts present an interesting problem, for, notwithstanding the direction of the wind, the annual fall of rain increases from west to east. For one cause of this distribution we may turn to the tropical cyclones which almost invariably move over the land from east to west, the precipitation diminishing as the distance from the Bay of Bengal increases. Another factor is the behavior of the two branches of the monsoons as the close of the rainy season approaches. The southwest branch often retreats toward the south first, and, as it withdraws, an indraught seems to be formed, so that its place is taken by the southeast winds from the Bay of Bengal. Consequently, while this latter wind blows, the rainfall of the region will diminish from east to west.

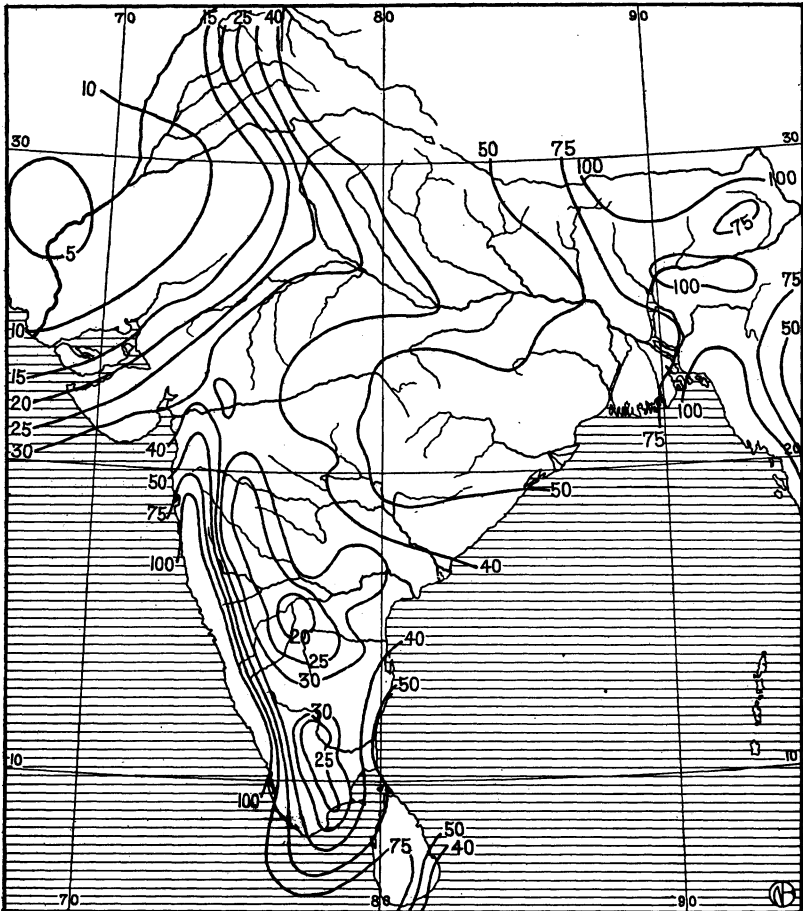
There remains to be considered the rainfall of the southern part of peninsular India, which differs from that of the other areas discussed in that the precipitation diminishes toward the interior from both the eastern and western coasts. This condition is readily understood on the western side where the Western Ghats intercept the southwest branch of the monsoons, causing very heavy rainfall on the western side of these highlands and leaving a correspondingly small supply for the area to the east of the mountains. As for the eastern side of the peninsula, the cyclones again help to explain the decrease from east to west. But the condition is accounted for to a much greater extent by the change in the direction of the summer monsoons as they retreat southward across the Bay of Bengal from the middle of September to the middle of December. During the early part of the summer the winds over the southern part of the bay blow from the south, but later, as in the case of central India, and to a greater extent than in those provinces, the winds are deflected toward the land, thus giving the southeastern portion of the peninsula, at that time, its heaviest rains for the year.

To understand the effects of India's rainfall, the average annual precipitation for the different provinces, as well as the variation in amounts for the several regions from year to year, must be known. The amount of rainfall within the year is often not so important as the distribution of that amount throughout the year.

H. F. Blanford showed that in India, as in other countries, rainfall varies most from year to year where it is smallest in amount, and that the supply is most constant where the fall is greatest. To explain variations in annual supply several reasons may be given. The number and intensity of the cyclones passing over the country may vary considerably from year to year, and thus one cause of variation is seen. The rains also may begin later than usual, or they may terminate earlier than in the normal season, or they may be reduced both by late beginning and by early retreat. Even with a normal advance and retreat of the monsoon there may occur "breaks in the rains," periods lasting perhaps for weeks, during which little or no rain falls, or there may be scanty fall for a part or the whole of the season. The factors of variation from year to year also suggest the reasons for differences in distribution throughout the year. For example, the times of advance and of retreat and the number and duration of the breaks in the monsoon, all play an important part in yearly distribution. The number, the intensity, and the time of the occur-

rence of winter and summer storms also exert an important influence on the annual distribution.

The life of man in India shows many responses both to the total amount of rainfall and to its distribution throughout the year. While there are many cases showing the immediate effect of dif-



Mean annual rainfall of India in inches. (After Eliot.) Scale, 1:27,000,000.

ferences in rainfall, there are a few showing the effect of long-continued influences upon the people. A good illustration is shown in the differing characteristics of the people of northern India. In parts of the Punjab and the adjacent provinces of northwest India the precipitation is slight. Constant struggle for

existence means the survival of the fittest and the consequent production of a hardy type of people. On the other hand, on the hot, damp rice fields of the Ganges delta the bountiful harvests make life easy. The weak are not eliminated as they are on the arid plains of the west. This region is occupied by a less hardy and less energetic people.

One proof of the difference in types of peoples in the two regions mentioned is shown by the outcome of conflicts between them and neighboring tribes. The population of the lower portions of the western Himalayas shows the effects of a marked intermixture with the people of the adjacent plains. This condition indicates successful raids by the hardy plains people into the country of their neighbors of the mountains, while there is little evidence of encroachment of mountaineers upon the plains. The weaker tribes of Bengal and Assam have been less fortunate. Here we find the Mongoloids of the mountains pressing to the very borders of the plains, with no proof of movement into the mountain region by the plains people.

Doubtless the effect of rainfall is shown more clearly in its relation to agriculture than in any other way. The kinds of crops which can be successfully produced in any locality must be selected on the basis of the amount of water needed by the crop. While it is evident that influences other than rainfall, such as temperature, irrigation, and character of soil, may aid in determining the crops raised, yet these other factors do not prevent one from tracing the direct effects of rainfall. The crops which require much rainfall or liberal irrigation for their successful cultivation are rice, jute, tea, or coffee. In regions in which the rainfall is heaviest as in Bengal, Assam, and the low valleys of the Western Ghats, rice is by far the most important crop. Sugar-cane is also grown in these wet provinces, but the areas given both to sugar and rice are, of course, not limited to regions in which rainfall alone gives sufficient moisture. The areas are constantly extended into regions in which rainfall is supplemented by irrigation, and even into regions like Sind, in which agriculture is wholly dependent upon irrigation. In regions in which rice is wholly dependent upon rainfall, it needs heavy rains at time of planting, frequent, moderate rains during growth, and a burst of rain in late stages to insure development of the grains. The rains of the later stages of growth are most important of all. For this reason, too early withdrawal of the monsoon rains has serious effect upon the rice crop. Rice growing is made possible in parts of the Central Prov-

inces because of the relatively large number of storms passing over this part of the country during the period of the summer monsoon. These regions lie in the low pressure trough between the southeast and southwest branches of the monsoon. Cyclonic storms exhibit a marked tendency to move along this trough of low pressure and variable winds. In some parts of the interior the rainfall of the wet monsoon occurs only during the passage of cyclones. There are many varieties of rice, and it is necessary that the planter know the conditions of rainfall, the character of the soil and the methods of cultivation to which each is best adapted. In parts of Bengal and Assam, which are more or less inundated at times of heavy rain, a variety of rice has been developed which lengthens its stalk as the water rises and is said to be able to keep the heads above eight or ten feet of water. It is often harvested from boats before the water subsides. Rice is commonly planted after the first heavy rains. Sugar differs from rice in time of planting, and indeed, from most other crops of India, in that the planting time is adapted to temperatures instead of to rainfall. It is planted in February or March before the hot season, as the young plants suffer from the hot sun.

The other crops requiring much moisture, *viz.*, jute, tea and coffee, differ from sugar and rice, in that their areas are not extended by irrigation but are limited to those regions in which water is supplied wholly by rainfall. The cultivation of tea requires not only a rather heavy rainfall but an atmosphere which is moist throughout the growing season. Dry winds are injurious. For this reason tea raising has not proved profitable in Chota-Nagpore, as the plants are injured by the dry winds of spring. The only provinces which are important for the growing of tea are Bengal and Assam, where the rains begin early, continue late in the season, and as a rule have few "breaks" or interruptions during the summer season. Coffee is grown chiefly in the hills of western Mysore and Coorg. The hills not only give the necessary elevation to which coffee is adapted, but they also intercept the moisture-laden winds of the southwest monsoon and thus supply the necessary precipitation. Incidentally, they also supply good drainage, an important feature, since flat and wet lands are not suited to coffee. Jute is a crop important only in Bengal. Conditions necessary for its cultivation are essentially the same as those for rice. The plant is, however, grown on rather high land, where there is sufficient rainfall during the whole period of growth. As it is a

crop which exhausts the soil, it is confined largely to regions in which inundation supplies regularly a new layer of silt.

Crops requiring less water are wheat, millets, pulses, and cotton. Wheat and cotton are injured by heavy rains, especially during later stages of growth. For this reason cotton, although a summer crop, is limited to those provinces having a comparatively light rainfall, as in parts of northern India and in the northern and central parts of peninsular India. In the latter region, it is grown chiefly on the black "cotton soil," which is very retentive of moisture, so that a satisfactory crop can be raised even where the rainfall is very light. Cotton is always a summer crop and is planted after the first rains. In peninsular India the crop in general is wholly dependent upon rainfall. Hence, failure of rains may mean loss of the entire crop. Unlike cotton, wheat is invariably grown in winter, a season in which the rainfall is less than that of summer, although in the central and western parts of northern India it is not the season of least rainfall. Irrigated wheat is grown in largest quantities in the Punjab, Rajputana, and the United Provinces, the water being obtained from canals and wells. When "dry crop" or unirrigated wheat is grown in these provinces it depends upon the moisture remaining in the ground at the end of the summer monsoon, and also upon the precipitation of the winter cyclones which are necessary for a full crop. In central India and the Central Provinces, where the winter rainfall is less than in northern India and where there is much less opportunity for irrigation, "dry" crop wheat is extensively grown on the moisture-holding black soil. Excellent crops are raised if the late summer rains are favorable. As wheat does best in cool climates, it is grown hardly at all south of the Central Provinces.

Except on the best-watered plains suitable for rice growing and in the important wheat-growing districts of northern India, the millets and pulses form the bulk of the food of the agricultural population. In regions in which rice is grown on the low lands as a "wet" crop, millet is usually grown on the higher lands as a "dry" crop. Hot weather millets require a heavy burst of rain at planting time, then frequent moderate rains for growth. Prolonged "breaks" in the rains for three weeks or more, accompanied by dry winds, affect the crop seriously. Of the pulses, some varieties are grown either as summer or winter crops, while others are grown only in the winter. Of the latter, the area sown varies with the character of the late rains. The chickpea is always a winter

crop. It is largely grown on the black soil as a "dry" crop, but in the north it is irrigated in regions of light rainfall or in particularly dry seasons. The pulses are often sown with wheat or other grains, so that in case of an unfavorable season, a harvest may be obtained from one sowing if not from the other. The size of the harvest, in case of the winter-grown pulse, is greatly influenced by the amount of winter rainfall, particularly in January.

Before deciding upon the particular crop to be raised, the Indian planter must take fully into account the amount and distribution of the rainfall of his locality and the relation which such rainfall bears to kinds of soil and to possibilities of irrigation. Not less carefully must he study the character of the precipitation in order to decide upon the number of crops per year, the rotation of crops, the times of planting and of harvest, and also the methods of cultivation. Two crops a year are raised in many parts of India, although in many cases the poor soils, combined with primitive methods of cultivation, do not permit two crops to be raised upon the same land in a given year. On the other hand, in such a province as Bengal, where rain falls throughout the greater part of the year and the land is constantly enriched by depositions of silt, two and sometimes three crops are grown on the same tract of land in one year. In most parts of the country the rainfall, in favorable seasons, is well adapted for two crops per year. The summer or autumn crops, as they are called, are sown in June or as soon as the ground has been softened by the monsoon rains. These, of course, depend for their moisture wholly upon the summer precipitation, while the autumn planting depends upon moisture remaining from summer rains and upon the rainfall of winter. In most parts of the country the winter rainfall, while very necessary for successful harvests, is small in quantity.

In central India, the double-cropped area varies according as the autumn rains are much or little. Seeds of the second crop are often sown in wet rice fields just as it is ready for the harvest. Even when the summer crops fail, autumn rains, supplemented by winter showers, make successful harvests possible for the latter season. In Bengal and Assam considerable rain falls from March to May, hence sowings may be made earlier than in other provinces depending upon rainfall. Much of the Bombay Presidency and the plains of the northwest receive no rain during the months of March, April and May, which are known as the hot season. In the plains of the Punjab, particularly, the intense heat and dryness of these months reduce the country to desert

conditions. Consequently agricultural pursuits are at a standstill during this period.

For the reason that rainfall is always scanty in certain parts of India, and that nearly all parts are subject to seasons of light rain, or of unsatisfactory distribution of rainfall, irrigation systems have been developed throughout the country. The regions receiving heavy rainfall, and consequently those in which chances of failure are remote, are Bengal and Assam and the strip of territory west of the Western Ghats. In other portions of India large areas would, without irrigation, be permanently waste, or could be cultivated only in years of exceptionally favorable rainfall. In still other regions having rainfall ordinarily sufficient, irrigation serves as security against seasons in which the rains fail in greater or less degree. When monsoon rains fail for one or two seasons in succession, agriculture in "dry" lands fails, while abundant harvests may be raised on irrigated areas. In times of scanty rainfall the limit between famine and plenty is the line between irrigated and non-irrigated lands.

Owing to differences in soil and topography, as well as to inequalities of rainfall, the character and extent of irrigation differs greatly in the several provinces. Irrigation by means of canals is not feasible if the rivers run in deep channels through the region which it is desired to water, or if the area has marked inequalities of surface, since the water in general is distributed by natural flow. For these reasons we find the largest canal projects in the plains of northern India and on the deltas of the east coast of the peninsula.

In northern India agriculture can be carried on in the province of Sind only where irrigation is possible. The Indus is to Sind what the Nile is to Egypt. Beyond the limits of irrigation all is a stony, sandy waste. Water is taken from the river by means of canals. No canal has its head where the river bank is really permanent, therefore the river must rise several feet before the canals can be filled. Many of the canals are former tributaries of the river which have been reopened and extended. Such simple methods of irrigation, however, make possible the cultivation of more than 2,000,000 acres of land, and thus enable this desert province to support a population of several millions.

East of Sind, in the Punjab and the United Provinces, while agriculture is by no means wholly dependent upon irrigation, the rainfall is so precarious that canal irrigation is necessary to prevent crop failures and consequent famine. Here are found

some of the largest government projects, such as the Bari Doab Canal, the East and West Jumna Canals, and the Ganges Canal. Some idea of the size of these undertakings is indicated by the fact that the entire volume of the Ganges at Hardwar, where it issues from the hills, is diverted into a canal and distributed to the level tracts of the United Provinces. Twenty miles farther down, the entire volume of the river is again diverted to irrigation channels. Some of the larger canals are from 150 to more than 300 miles in length. Irrigation works of large proportions are possible in this part of the country because of the comparatively level land, and, what is more important, because of the large snow-fed streams issuing from the Himalayas. In these provinces more than 2,000,000 acres are irrigated by government projects. In addition to these canals, water is also obtained from wells, particularly in the north near the Himalayas, and from inundation canals on the southern plains. On areas not reached by irrigation, "dry" crops are raised; these necessarily fluctuate with the amount and distribution of rainfall.

The only other portions of India in which canal irrigation is carried on extensively are the deltas of the east coast of the peninsula. The chief rivers entering the sea on the eastern side of the peninsula are the Mahanadi, the Godavari, the Kistna, and the Cauvery. In the upper part of their courses these rivers run in deep channels and so drain the land instead of irrigating it, but as they enter upon the plains of the coast, dams are thrown across them, thus permitting the water to be diverted to extensive irrigation works. The deltas of these rivers are covered with crops which, because of the excellent system of irrigation, almost never fail.

While irrigation by means of canals is necessarily limited to the few areas in which conditions are favorable, irrigation by means of tanks or storage-works is to be found in all provinces except Sind and the Punjab. Canal irrigation is adapted particularly to those areas in which the river flow is fairly constant for the whole or the greater part of the year, as south of the Himalayas, where the rivers are supplied by the melting snows of the mountains. On the other hand, tanks are used where the drainage flow is intermittent or varies greatly in quantity, as in many of the smaller streams of peninsular India. These tanks, which are formed by damming the streams, vary in size, from lakes in which are impounded several billions of gallons to the small tank which supplies only a few acres. However, the area

supplied by large tanks is small as compared with the total area supplied by the many smaller tanks constructed chiefly by the owners or tenants of the lands with little assistance from the government. Water is supplied by thousands of these smaller tanks in Madras, where they are found to a much greater extent than in any other part of India. Other regions of irrigation by storage tanks are the Gujarat and Carnatic Districts of the Bombay Presidency, the Deccan, and the Central Provinces. In the latter provinces the tanks are nearly all small private reservoirs, although in the aggregate they supply about 500,000 acres. Generally speaking, the broken character of the surface of practically the whole of peninsular India offers little facility for canal irrigation. It is better adapted to irrigation in small regions of variable extent by wells, tanks, and small streams.

The other method of irrigation, which has already been referred to, is by means of wells. This type differs from the types previously described, in that the works are always on a very small scale and irrigate areas varying in size from one to twenty acres. In the aggregate more than thirty per cent. of the irrigated land of India is watered in this way. Seventy per cent. of the land thus irrigated is in the Punjab and the United Provinces, where the alluvial plains offer the most favorable conditions for well irrigation. Wells are also found in the Madras and Bombay Presidencies. In the Central Provinces, where the rainfall is slight, ground-water is found only at great depths, thus making well irrigation impracticable. In certain parts of India the well water contains nitrates. In parts of Gujarat large crops of tobacco are raised year after year with no fertilization of the soil except that obtained from nitrates in the irrigation water. In the cattle-raising districts of Rajputana water from wells is practically the only source of supply. Well irrigation becomes increasingly difficult as depth of ground water becomes greater, first, because of increased cost of constructing the well, and, second, because of the cost of operation. In nearly all cases in which the well water is not near the surface the operating cost by this method is greater than that by canals and tanks, because, by the latter methods, water is distributed by natural flow.

Irrigation not only greatly increases the area given to agriculture, but it renders more secure against precarious rainfall the crops of a large proportion of the country. Indeed, irrigation is regarded as a form of insurance against famine. From earliest times India has suffered from famines, the area varying with the

extent of failure of the rains. The regions most likely to have famines are the western and southern districts of the United Provinces, the Punjab south and east of the Sutlej, eastern Rajputana, and the larger portion of peninsular India south of the Central Provinces and east of the Western Ghats.

In northwest India failure may be due to one or more of the causes which prevail over a great part of the country, such as late beginning or early termination of the monsoon rains, "breaks" in the rains, or scanty fall for greater or less portions of the monsoon period. One cause of "breaks" is the displacement northward of the axis of low pressure lying between the southeast and southwest branches of the summer monsoons. This movement diverts the southeast monsoon winds from their usual course and allows their place to be taken by hot, dry winds from the arid plains to the northwest. Famine is almost sure to occur in northern India if, in addition to loss of summer rainfall, there is also failure of winter rains upon which the planter depends for the success of his spring or winter crops. With the assistance of October rains, which moisten the earth for sowing cold weather crops, two bumper harvests have been obtained from an annual rainfall aggregating only one-third the average. Such a case is a good illustration of the importance of the favorable distribution of rainfall throughout the year.

In central India and the Central Provinces complete failure of the rains almost never occurs. Famine is usually due to several indifferent years followed by one in which rainfall is very slight. In the black soil region of the western districts famine is almost wholly unknown owing to the ability of the soil to retain moisture. In the great famine of 1899-1900 the suffering would have been much less had not the dry season included the critical weeks of late summer. If rainfall up to the end of October is sufficient, the success of both crops is assured, although showers in November and December are necessary to produce heavy spring crops. During the famine of 1900 the inhabitants of Malwa, one of the provinces of the black soil region, were wholly unprepared, the people then living never having experienced famine. Inhabitants of regions subject to famine often migrate to provinces where food can be obtained. Conditions at this time in Malwa were rendered much worse by an influx of people from Rajputana, who, in previous famines, had obtained food in Malwa.

The eastern part of peninsular India receives rainfall both from the southwest branch and from the retreating southeast branch

of the summer monsoon. Therefore crops in these regions, depending for their water supply upon rainfall, suffer from failure of either of these rains. Obviously, conditions are most serious when both rains fail. The Orissa famine of 1866 was due to very early termination of the ordinary southwest monsoon in 1865, and to the failure of the retreating monsoon the same year. The Madras famine of 1833 was due to a partial failure of the southwest monsoon followed by complete failure of the retreating monsoon. Similar conditions were the causes of famine in 1854 in Bellari, Madras and Hyderabad, except that in the preceding year the rainfall was exceptionally heavy and the crops unsatisfactory. On the Plateau of Deccan the people hardly expect more than two good crops in five. Here famine is due to one or more bad seasons followed by complete failure of the southwest monsoons. The irrigated crops of Madras as well as the dry crops are dependent upon the retreating monsoons. The planter depends very largely upon these rains to fill the irrigation tanks. Hence failure of the retreating monsoon rains may result in loss even of irrigated crops, and famine follows.

In former times, famines and scarcity were more frequent and widespread than in recent years. It is only since the country has been controlled by Great Britain that the larger irrigation works have been developed, particularly the large canal projects of northern India. Another reason for the greater suffering of earlier times was the lack of means of communication between afflicted provinces and those in which food might be obtained. In addition to an increase in the area of irrigated lands, scarcity and famine are now much more readily relieved by the multiplication of railroad lines constructed by the British. To-day, when crop failure occurs in a province, the consequent rise in prices diverts to that region products of other provinces which otherwise might be exported to foreign countries.

While crop failure may be prevented in considerable degree by irrigation, and while the effects of such failures may be relieved by increased transportation facilities and government aid, yet the real cause of famine, the failure of the rains, cannot be controlled by man. As the very life of the people depends upon the precarious rainfall of large areas of India, the government has established and maintained one of the best meteorological services in the world. In order that rainfall conditions may be anticipated as far as possible, the service attempts to forecast the character of the summer monsoon and its rainfall. Some of the data used

as the basis of this forecast are the amount of snowfall in the Himalayas during the preceding winter, the strength of the south-east trades before crossing the equator, the character of the rainfall in the southeast trade region in the southern hemisphere, and the pressure conditions in the different provinces. It has been found that heavy and late snowfall in the Himalayas is likely to be followed by a late summer monsoon, giving scanty rainfall, particularly on the Bombay side of the peninsula. This method has been used successfully in forecasting failure of the rains. It has also been found that there is a close relation between the rainfall in the southeast trade region in the period November to April and the rainfall of the Arabian branch of the Indian monsoon. That is, a light rainfall in the southeast trade region is either preceded or followed by a weak monsoon in India. In such years the southwest branch advances late, retreats early, and gives less rain than usual over the whole area dependent upon it. The distribution over India of the precipitation of any monsoon is predicted on the basis of the pressure conditions existing in the different provinces for some time preceding the advance of the monsoon. The wind currents are directed particularly to those areas in which the pressure has been persistently low, and are diverted from those areas in which the pressure has been persistently high. What is still more important, these differences in pressure, once established, are likely to be maintained throughout the summer monsoon period, and are therefore one of the most important elements in making possible a forecast for the different parts of the country. The forecasting of the character and rainfall of the summer monsoons in India is particularly interesting, in that it furnishes the only instance in which long-range seasonal forecasts have been at all successful.

In the discussion of agriculture the want of closer relation between rainfall and products was explained as being due to the presence of other influences such as character of soil and irrigation projects. The same statement could be made with reference to the effect of the rainfall of the several portions of the country upon the distribution of population. Notwithstanding the presence of these other causes, a glance at the population maps shows the greatest density where rainfall is heaviest and therefore most reliable, and least density where rainfall is lightest and most precarious. It is easy to see that sufficient and dependable rainfall, making good harvests possible every year, would naturally lead to denser population than a scanty and irregular rainfall, permitting

harvests only of moderate size in ordinary years, and meagre crops, or none, when the rains fail. But in addition to this direct relation between rainfall and population there are other less apparent but equally effective ways in which the number of people is influenced by the amount and distribution of rainfall. For example, in addition to an increased death rate, failure of crops also produces a noticeable reduction in the birth rate due in part to the smaller number of marriages at such a time. The marriage ceremony involves great expenditure: crops are necessary in order that the money be obtained. Consequently, with failure of the crops, marriages are deferred, and the able-bodied men go to other places in search of work. With recurrence of good harvests the people return, deferred marriages are celebrated, and the increase in population is soon apparent. Moreover, the supply of food has direct effect upon the health and in consequence upon the birth rate as well as upon the death rate. A marked increase in the cost of food, following crop failure, causes an immediate increase in the death rate, and a decrease in the birth rate nine months later. Any considerable reduction in the cost of food produces the opposite effect. Even in the normal season, the birth rate and death rate fluctuate with varying food supply. In general, if the principal harvest is gathered in October there is a sudden rise in the birth rate the following July, increasing to a maximum in September or October. From this time there is a gradual fall in the birth rate to the minimum in June. Where the chief crop is harvested in December, the rise in the birth rate occurs at a correspondingly later period. On irrigated lands, where crops are secure, the birth rate is uniformly high.

The large number of deaths occurring at times of scarcity or famine, while due in part to actual want of food, is probably due in greater measure to the prevalence of disease among the people, which their weakened bodies are unable to resist. Moreover, the peculiar conditions incident to abrupt changes in the rainfall are particularly favorable to the spread of certain types of diseases. The effect of heavy and continuous rains is to wash accumulated soil impurities into the water sources and to leave stagnant collections of water where drainage is defective. Wells fill too rapidly for the water to be purified as it passes through the soil, hence it is unfit for drinking purposes. The change from dry season to wet is accompanied by an abrupt change in the food supply, coarse vegetables taking the place of the dry grains. Where there is rice cultivation the natural drainage is interfered with and in-

sect and micro-organic life multiplies rapidly. Thus with the coming of the rainy season there is a marked increase in the death rate. This rise in the early part of the monsoon rains is due to dysentery, diarrhea and cholera, which are, in part at least, caused by impurities in the water supply. Fevers are prevalent during the latter part of the wet season. The dry season likewise has its unhealthful conditions. As the rains cease and the moisture evaporates the water supply becomes greatly reduced. The only supply is muddy puddles, and rivers which may have been reduced to a chain of muddy pools. If the monsoon fails, conditions are aggravated, the water supply is polluted by bathing, by the washing of clothes, and by the watering of cattle. In this way the plague of cholera is added to the suffering due to famine.

As stated at the beginning, many more cases of response to rainfall conditions in India could easily be shown, and those considered in this article could very profitably be more fully worked out. But what has been suggested here, though perhaps only a beginning, certainly shows an exceedingly close relation between the rainfall of India and the life of man in that country.